Trouble at the Top of the Food Chain: Environmental Contaminants and Health Risks in Marine Mammals

A White Paper on Research Priorities for Fisheries and Oceans Canada

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TROUBLE AT THE TOP OF THE FOOD CHAIN: ENVIRONMENTAL CONTAMINANTS AND HEALTH RISKS IN MARINE MAMMALS-

A WHITE PAPER ON RESEARCH PRIORITIES FOR FISHERIES AND OCEANS CANADA

by

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Abstract

Ross, P.S., Stern, G.A., and Lebeuf, M. 2007. Trouble at the top of the food chain: environmental contaminants and health risks in marine mammals - A white paper on research priorities for Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2734: viii + 30 p.

Marine mammals comprise a number of charismatic species that are vulnerable to adverse health effects associated with exposure to environmental contaminants, notably those considered to be persistent, bioaccumulative and toxic (PBT; includes various organic and metallic contaminants). The vulnerability of marine mammals can be attributed to their often long lifespan during which they can accumulate persistent contaminants, their often high position in aquatic food webs which leads to a biomagnification of PBTs, and their inability to readily eliminate many of these contaminants. In addition, several other classes of contaminants, including some pesticides, metals and hydrocarbons, may present a risk to the health of marine mammals that do not occupy high positions in food webs (such as sediment-filtering grey whales), or a risk to their prey. Marine mammals can be considered as the ultimate 'biological sinks' for thousands of chemicals released into Canada's oceans. Understanding how different chemical contaminants move into marine mammal food webs, and what the impacts of these are on the health of marine mammals or their prey, represent two fundamental knowledge needs for scientists, conservationists, managers and regulators. Fisheries and Oceans Canada (DFO) plays a vital role in the stewardship of the 40 + marine mammal species inhabiting Canadian waters, be it from the perspective of ecotourism, harvesting (First Nations and otherwise), their role as top predators in food webs, or their intrinsic value to Canadians. Environmental contaminants are cited as conservation threats to the Species At Risk Act (SARA)-designated 'threatened' beluga whales of the St Lawrence estuary, and the 'endangered' and 'threatened' resident and transient killer whales of British Columbia. Marine mammal toxicology research by DFO scientists delivers 'integrated' state of the environment reporting to managers, information on the factors affecting the health (mortality, reproduction, development) of threatened or endangered marine mammal populations, and a unique means of communicating information to the general public and key stakeholder groups. Contaminant research in marine mammals has delivered advice to DFO SARA Recovery Teams, Oceans programs (Marine Environmental Quality [MEQ] and Integrated Management [IM]), and Habitat projects, and has been used to improve conservation or mitigation program delivery by Other Government Departments (Environment Canada, Health Canada, Indian and Northern Affairs Canada), transboundary agencies and efforts (United States Environmental Protection Agency, National Marine Fisheries Service, Stockholm Convention) and Non-Governmental Organizations (NGOs). Priority research needs for DFO include contaminant biomarker development and application ('health effects'), pathways research to understand why marine mammals become highly contaminated and to assess the potential effects of climate variation on exposure, an ecosystem context which documents the conservation impacts of toxic chemicals, the assessment of emerging contaminant risks to marine mammals, and exposure assessments in vulnerable environments such as the Arctic.

Résumé

Ross, P.S., Stern, G.A. et Lebeuf, M. 2007. Des problèmes au sommet de la chaîne alimentaire: les contaminants de l'environnement et les risques pour la santé des mammifères marins – un document de discussion sur les priorités de recherche de Pêches et Océans Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2734: viii + 30 p.

Les mammifères marins comprennent plusieurs espèces qui exercent une grande fascination sur les humains mais sont vulnérables aux effets sanitaires nocifs associés à l'exposition aux contaminants de l'environnement, notamment ceux qui sont classés parmi les contaminants persistants, bioaccumulatifs et toxiques (abrégés « PBT »; ils incluent divers contaminants organiques et métalliques). La vulnérabilité des mammifères marins peut être attribuée à leur durée de vie souvent longue pendant laquelle ils accumulent des contaminants persistants, à la grande fréquence avec laquelle ils se trouvent au sommet des réseaux alimentaires aquatiques, ce qui entraîne la bioamplification des PBT et leur incapacité à éliminer facilement un grand nombre de ces contaminants. En outre, plusieurs autres classes de contaminants, notamment certains pesticides, métaux et hydrocarbures, peuvent présenter un risque sanitaire pour les mammifères marins qui ne se trouvent pas au sommet de la hiérarchie alimentaire (comme les baleines grises qui filtrent les sédiments) ou un risque pour leurs proies. On peut dire que les mammifères marins constituent les « trappes biologiques » suprêmes des milliers de produits chimiques rejetés dans les océans du Canada. Comprendre comment différents contaminants chimiques pénètrent dans les réseaux alimentaires des mammifères marins et quels impacts ils ont sur la santé de ces derniers ou de leurs proies constituent deux besoins fondamentaux de connaissances chez les scientifiques, les conservationnistes, les gestionnaires et les responsables de la réglementation. Pêches et Océans Canada (MPO) joue un rôle crucial dans la gérance des plus de 40 espèces de mammifères marins fréquentant les eaux canadiennes, que ce soit du point de vue de l'écotourisme, de l'exploitation des ressources (par les Premières nations et autres parties), leur rôle de prédateurs de niveau trophique supérieur ou leur valeur intrinsèque pour la population canadienne. Les contaminants de l'environnement sont mentionnés comme autant de menaces à la conservation des bélugas de l'estuaire du Saint-Laurent, une espèce menacée en vertu de la Loi sur les espèces en péril (LEP) et les orques résidents et nomades « menacés » et « en voie de disparition » de Colombie-Britannique. La recherche toxicologique sur les mammifères marins réalisée par les scientifiques du MPO fournit un état de l'environnement « intégré » aux gestionnaires, des renseignements sur les facteurs touchant la santé (mortalité, reproduction, développement) des populations de mammifères marins menacées ou en voie de disparition ainsi qu'un organe unique de communication de l'information au grand public et aux groupes d'intervenants. La recherche sur les contaminants chez les mammifères marins a fourni des conseils aux équipes LEP de rétablissement du MPO, aux programmes Océans (Qualité du milieu marin [QMM] et Gestion intégrée [GI]) ainsi qu'aux projets Habitat; elle a également été utilisée en vue d'améliorer la mise en œuvre de programmes de conservation ou d'atténuation des impacts par d'autres ministères gouvernementaux (Environnement Canada, Santé Canada, Affaires indiennes et du Nord Canada), des initiatives et organismes transfrontaliers (United States Environmental Protection Agency, National Marine Fisheries Service, Convention de Stockholm) et des organisations non gouvernementales. Les besoins prioritaires du MPO en matière de recherche comprennent le développement et l'application de biomarqueurs de

contaminants (« effets sanitaires »), la recherche sur les voies de pénétration afin de comprendre pourquoi les mammifères marins sont atteints d'une contamination aussi élevée et l'évaluation des effets éventuels des variations climatiques sur l'exposition, une approche écosystémique qui documente l'incidence, en matière de conservation, des substances chimiques toxiques, l'évaluation de nouveaux risques relatifs aux contaminants pour les mammifères marins et des évaluations de l'exposition dans des milieux vulnérables comme l'Arctique.

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1 Introduction

Marine mammals merit special mention in the context of the study of contaminants and contaminant-associated effects in Canada. While the marine environment is often considered the ultimate 'sink' for thousands of point-source and non-point source pollutants, marine mammals are particularly vulnerable to the consequent health effects of these releases. Marine mammals are vulnerable as a result of their often very long lives (up to 200 years), their feeding ecology which predisposes them to high exposures (e.g. top of the food chain or in the sediments), and their difficulty in eliminating many pollutants. Fisheries and Oceans Canada has a stewardship responsibility towards these mammals, with scientific research providing a basis for management, conservation, protection and outreach. In addition, studies on marine mammals can provide important state of the environment reporting, with several species providing integrated contaminant signals from coastal food webs.

Canada is home to over 40 species of marine mammals, including Pinnipeds (seals, sea lions and the walrus) and Cetaceans (whales, dolphins and porpoises), as well as polar bears and sea otters. While marine mammals have members from several evolutionary lineages, they do share certain biological and ecological features that provide for their grouping into a designation of 'marine mammals' ('aquatic mammals' is more accurate as several members live exclusively in freshwater, such as the Ungava harbour seal in northern Quebec and the Baikal Seal in Russia). They are all warm-blooded, air breathing animals that rely primarily, if not entirely, on an aquatic existence and on aquatic prey. Marine mammals are generally long-lived, have large habitat needs, and have faced numerous historical conservation threats associated with human hunting pressures and other anthropogenic activities. Many populations or species have not recovered from hunting or whaling, as evidenced by Canada's listing of 33 marine mammal species under SARA.

Environmental contaminants, especially those that are persistent, bioaccumulative and toxic (PBT), represent a particular threat to marine mammals, with these species having long lives and high positions in aquatic food webs. PBT chemicals, also known as Persistent Organic Pollutants (POPs), include the polychlorinated biphenyls (PCBs), the polybrominated diphenylethers (PBDEs), dioxins, furans and the organochlorine pesticides (Fig. 1). Several species (or populations) are predisposed to heavy contamination by persistent organic pollutants (POPs), mercury (Hg) and other bioaccumulative chemicals. Many contaminants present in the Canadian environment are considered endocrine-disrupting, and observations of immunotoxicity, reproductive impairment, and developmental abnormalities in some marine mammal populations highlight the population-level consequences of such contamination. These contaminants have been shown to move great distances through atmospheric transport, resulting in deposition in remote regions (Fig. 2).

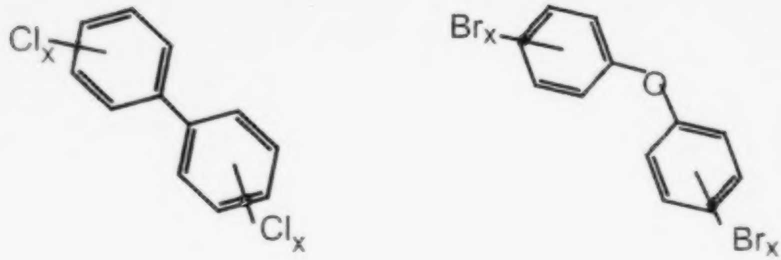

Figure 1: Two examples of persistent, bioaccumulative and toxic chemicals. On the left, the basic structure of the now largely banned polychlorinated biphenyl (PCB) molecule. It was banned in Canada in 1977. On the right, the currently used flame retardant chemical polybrominated diphenylether (PBDE). Both chemicals have a theoretical maximum of 209 different congeners, with permutations reflecting number and position of the halogen in question (chlorine for PCBs, bromine for PBDEs).

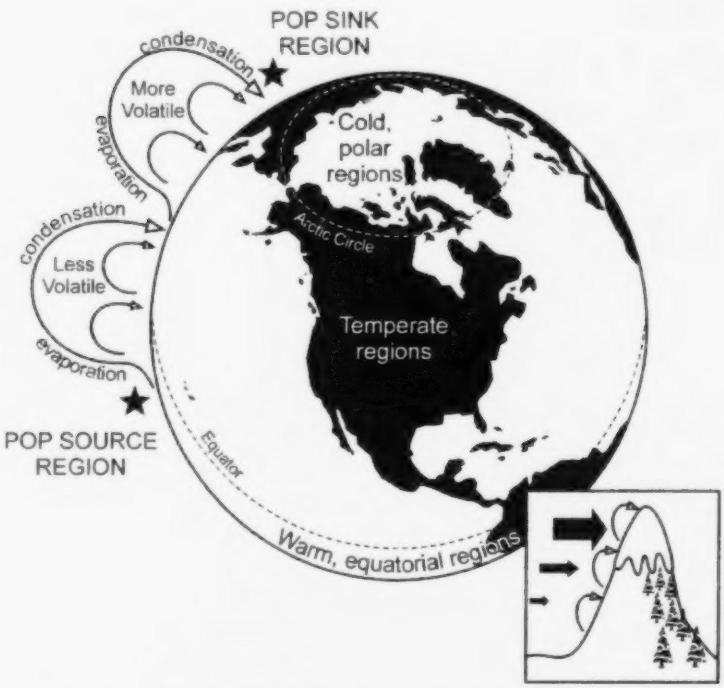

Figure 2: Persistent organic pollutants (POPs) are readily transported through atmospheric processes from industrial, agricultural and urban sources to remote environments, including the Canadian Arctic. Once deposited onto water surfaces, these fat-soluble chemicals rapidly attach to particles or bind to fat components at the bottom of the food web. The same process can lead to a 'cold condensation' process at upper elevations in mountain ranges. From (Ross and Grant 2007).

Marine mammal toxicology provides useful information about the state of marine ecosystems in all three of Canada's oceans. High profile contaminant research has been carried out by DFO and other researchers in all three of Canada's oceans, with work on species including Pacific killer whales, and beluga whales in the Arctic and the St Lawrence. The following conceptual groupings describe in general terms the utility of conducting contaminant-related marine mammal research by DFO scientists:

1) *Contaminants as conservation threats to marine mammal populations.* Marine mammals are vulnerable to contaminant-related adverse health effects associated with endocrine disruption. Reduced reproductive health, increased susceptibility to disease, the appearance of lesions and tumours, and increased incidence of developmental abnormalities, have been observed in contaminated marine mammal populations. These contaminant-associated effects can threaten a population or slow the recovery of a species at risk. Contaminants represent high priority action items for Recovery Teams responsible for St Lawrence beluga whale and British Columbia killer whale populations under the auspices of the Species at Risk Act (SARA).

2) *Marine mammals as indicators of environmental contamination.* The long lifespan and high trophic level of many marine mammals renders them vulnerable to the accumulation of often very high concentrations of PBTs. In this way, marine mammals can integrate contaminant signals from marine food webs and generate a 'state of the environment' report which provides a picture of the 'real world' of environmental contaminants of use to managers, policymakers and the general public. Since marine mammals are exposed to the cumulative effects of countless point- and non-point contaminant sources, they represent global biological 'sinks' for the persistent contaminants released by human activities. Contaminants and health effects in marine mammals inhabiting Canada's three oceans are playing important roles in indicator programs in support of marine environmental quality and 'state of the environment reporting' under the terms of the Oceans Act and other legislative needs.

3) *Marine mammals as 'canaries in the coal mine' for human health.* Contaminated marine mammals, or marine mammal populations that exhibit contaminant-related health effects, may warn us about possible human health risks associated with a heavy reliance on a shared food web. While human health issues are not a direct responsibility of DFO, the study of marine mammal toxicology provides a critical piece of important information on the state of traditional foods of First Nations and Inuit. This concept provides for important linkages to several government departments that do not have an expertise in the area of marine mammals or marine food webs, including Health Canada, Indian and Northern Affairs and Environment Canada. In fact, it was the highly effective multi-agency collaborations on the contamination of the Arctic food web (spanning fish to ringed seals, polar bears, beluga whales and Inuit peoples) that enabled Canada to successfully rally recent international support to establish and ratify the Stockholm Convention (http://www.pops.int/) on phasing out priority POPs on a global scale. This treaty was a global breakthrough in protecting aquatic food webs far removed from pollution sources, and is an important means of protecting vulnerable species including marine mammals.

2 Exposure of marine mammals to contaminants

While fish and invertebrates can be exposed to contaminants through both diet and gills, marine mammals are exposed to environmental contaminants almost exclusively through dietary uptake (with the notable exception of such acute exposures as oil spills). Having a good understanding of their food webs is therefore critical to interpreting contaminant concentrations and patterns in a given marine mammal, and in estimating exposure-related risk (Fig. 3). Understanding the dynamics of contaminants in marine mammals over time (seasons) and among compartments (tissues) is an important part of evaluating exposure, accumulation, and effects (target tissues). In addition, such knowledge can assist in the design of management strategies and risk-reduction measures, as contaminant sources may be partly elucidated through an understanding of food webs and marine mammal feeding preferences.

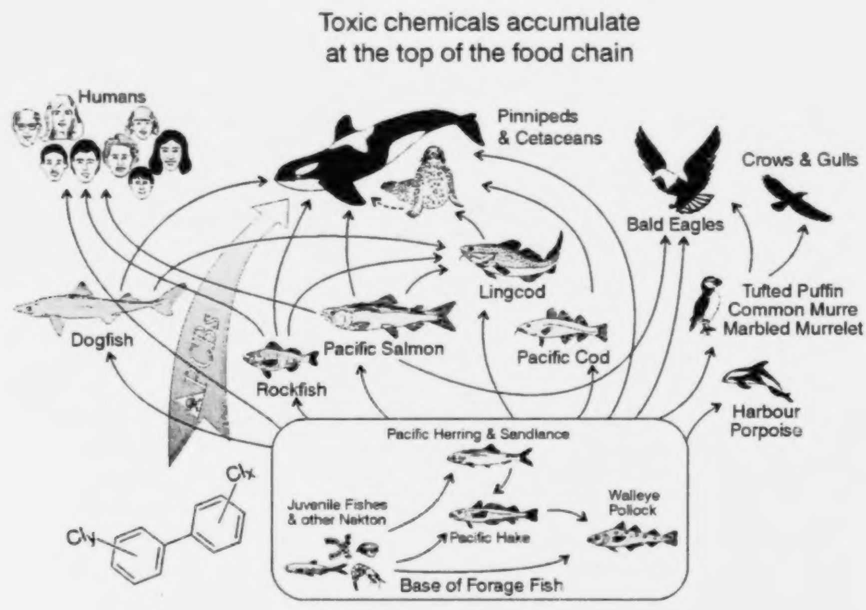

Figure 3: The structure of the aquatic food web underlies the accumulation of persistent organic pollutants in marine mammals, with high trophic level species being vulnerable to heavy contamination (adapted with permission from (Ross and Birnbaum 2003))

Concentrations (and hence health risks) of environmental contaminants vary by trophic level in a food web, proximity to contaminant sources (spatial), and over time. Several Canadian studies have documented that those marine mammals that consume other marine mammals are more POP-contaminated than those that consume fish or invertebrates (Muir *et al.* 1995;Ross *et al.* 2000); the impact of industrial contamination 'hotspots' (Massé *et al.* 1986;Ross *et al.* 2004); and have documented temporal trends for several contaminant classes, both downwards (reflecting regulations and source control) and upwards (reflecting current use and disposal) (Addison and Smith 1998;Addison *et al.* 1998;Ikonomou *et al.* 2002;Lebeuf *et al.* 2004). These studies help to

focus DFO marine mammal research related to adverse health effects and about habitat quality (see Figure 4). Marine mammal research can provide important overviews of emerging PBT contaminants in the Canadian environment.

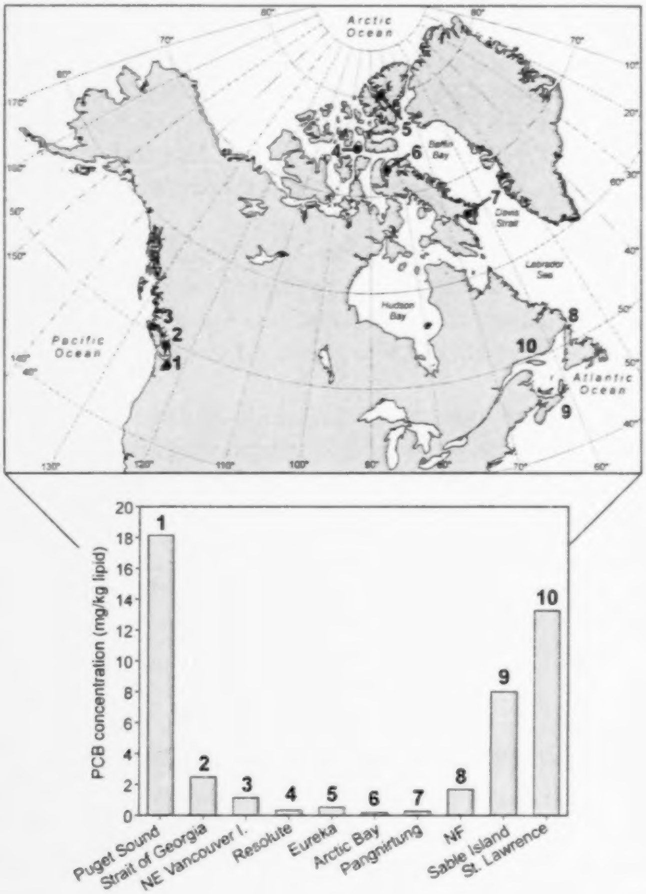

Figure 4: Despite the contamination of traditional Inuit foods (char, seals and beluga whales) in the Arctic, high PCB concentrations in pinnipeds (young harbour and ringed seals) closer to industrial activities reveal the greater degree of marine food web contamination in the south. Data from (Ross *et al.* 2004;Sjare *et al.* 2005;Muir *et al.* 2000;Bernt *et al.* 1999;Addison and Stobo 2001).

There are several exposure-related concepts that are relevant to health-related risks to marine mammals, and must be incorporated into study designs for field, semi-field, and captive marine mammal research. These considerations must also be incorporated into the interpretation of trends over time, and the factors affecting e.g. recovery following source controls. These include:

1) *life history features* - marine mammals are of special concern owing in large measure to their long lives. Exposure must therefore be considered in the context of emissions

histories on a chemical-by-chemical basis over long periods of time, and consequence variations in the contamination of their prey (Hickie *et al.* 2000).

2) *diet* – where feeding ecology, trophic level, and food web structure must be considered. For example, there are marine mammals that consume fish, while others consume marine mammals, filter plankton, or sift through sediments for invertebrates.

3) *location* – where proximity to contaminant sources must be considered. Localized contaminant 'hotspots', such as harbours, can expose local marine mammal food webs to contaminants. On the other hand, migratory fish such as salmonids may accumulate non-point source contaminants from the open ocean.

4) *transplacental transfer and lactation* – newborn marine mammals are largely exposed to persistent contaminants that are transferred via the lipid-rich (30-45% fat content) mother's milk. Documenting such exposure features is important in the characterization of health risks in marine mammal populations.

5) *degradation products* - the mammalian liver employs a battery of detoxifying enzymes to breakdown and eliminate certain compounds. However, the by-products are often highly reactive intermediates, and have been shown to elicit toxic effects in marine mammals.

6) *pharmacokinetics* – understanding tissue distribution and factors affecting contaminant burdens (e.g. seasonal cycles, fasting) represents an important part of understanding health risks to marine mammals.

3 Effects of contaminants on marine mammal health

The health of marine mammals can be affected as a result of 1) chronic exposure (i.e. through the ingestion of contaminated prey), 2) their prey base being affected by contaminant-related toxicities, or 3) direct (acute) contaminant exposure (e.g. oil spill)(Fig. 5). The extent to which a marine mammal population faces risks associated with contaminant exposure depends on the biology of the marine mammal in question (sensitivity to a particular chemical, feeding preferences, habitat use, and life history features, and the behaviour of the particular contaminant in the environment (source, transport and fate characteristics of a given chemical).

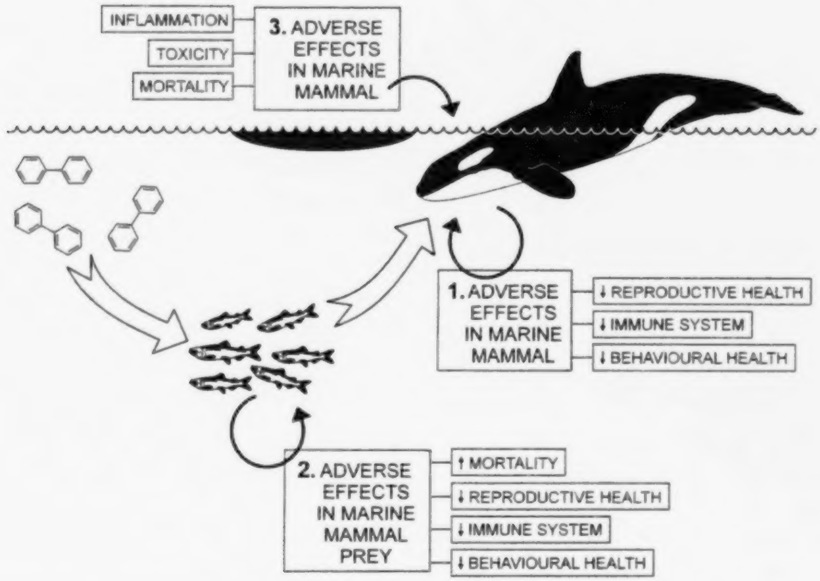

Figure 5: Food webs are central to the topic of marine mammal toxicology. While marine mammals occupying high positions in aquatic food webs are vulnerable to the endocrine-disrupting effects of persistent organic pollutants (POPs) ingested via their prey, chronic effects may be manifested either through 1) an impact on the development or health of the marine mammal in question, and/or 2) an impact on the health (quality or quantity) of their preferred prey, and/or 3) a direct impact associated with exposure to a contaminant such as oils or fuels.

The presence of chemical contaminants in marine mammals may exacerbate the effects of other (emerging) threats to marine mammals such as 'biological pollutants'. For example, it is thought that the introduction of a new virus (phocine distemper virus or PDV) into a contaminated population of harbour seals in northern Europe caused a more severe disease outbreak (60% mortality rate) as a consequence of a contaminant-associated suppression of normal immune function (Ross *et al.* 1996a;De Swart *et al.* 1996).

Different chemical contaminants exert their health impacts in different ways, and marine mammals are exposed to hundreds of contaminants through the consumption of prey or through metabolic conversion to more toxic products. Establishing mechanistic (causal) linkages between a single chemical class and a defined health effect in wild marine mammals is therefore a challenging task. In addition, designing studies that would address such causal linkages in marine mammals (e.g. captive dosing studies) are considered unethical, and would likely suffer from a lack of relevance to the 'real world'. However, a 'weight of evidence' approach has increasingly been adopted as a means to estimate risks to contaminated marine mammal populations (Ross 2000). The following summarizes the approaches used to document linkages between contaminant exposure and adverse health effects in marine mammals:

1- *Captive dosing with single chemical class*. Legal, ethical and societal values generally limit such approaches to laboratory animal models (e.g. rodents). As with human

toxicology, such models can be effectively used to estimate risks in marine mammals that link particular chemicals to specific health effects. In the past, those studies did evaluate some of the effects of acute exposures to petroleum hydrocarbons in ringed seals and polar bears (Engelhardt *et al.* 1977).

2- *Captive feeding studies of marine mammals*. Two major captive feeding studies in the Netherlands using harbour seals fed fish from either contaminated or uncontaminated regions have provided a basis for understanding the effects of complex mixtures of POPs on marine mammals. The captive feeding scenario enables the elimination of confounding factors as well as serial blood samplings. The group of seals fed the more POP-contaminated fish suffered from reproductive impairment, disruption of thyroid hormones and vitamin A, and reduced immune function (De Swart *et al.* 1996;Ross *et al.* 1996a;Reijnders 1986).

3- *Epidemiological studies of free-ranging marine mammals*. Several research groups have observed correlations between health endpoints and POP concentrations in different species of free-ranging marine mammal. While some studies have suffered from confounding factors which preclude firm conclusions, several have detected POP-related impacts, including altered vitamin A, thyroid and immune function endpoints (Simms *et al.* 2000;Levin *et al.* 2005;Tabuchi *et al.* 2006;Mos *et al.* 2007;Mos *et al.* 2006).

4- *Demographic studies in marine mammals*. While lacking in terms of mechanistic understanding, observations of reduced recruitment, increased mortality, or histopathological lesions typical in marine mammals inhabiting contaminated regions form an important part of the evidence of population-level impacts of contaminants (De Guise *et al.* 1995;Helle *et al.* 1976;Martineau *et al.* 1988).

5- *In vitro*-based laboratory testing. Cells or cell lines isolated from marine mammals have been used to characterize the *in vitro* effects of different chemicals. Such approaches may provide insight into the identification of the toxicity of particular chemicals, add mechanistic understanding to field observations, or provide a basis for inter-species extrapolation (Levin *et al.* 2004;Gauthier *et al.* 1999).

6- *A 'weight of evidence'* that captures all of the above points provides the most rigorous means of characterizing the risk of adverse health effects in a given marine mammal population. Such an exercise involves extrapolation across species, relies on the conserved nature of physiological endpoints among vertebrates, must be carried out critically, and approximates the process used to assess human health risks associated with contaminant exposures (Ross 2000;Ross and Birnbaum 2003).

4 Hot topics in marine mammal toxicology in Canada

4.1 *Case study 1*: St Lawrence estuary Beluga whales (*Delphinapterus leucas*)

The beluga whale population inhabiting the St Lawrence Estuary (SLE) is unique in that it is the most southerly located population in the world. The presence of beluga in this area constitutes a positive value for local ecotourism and whale watching activities. A clear interest in the St Lawrence beluga population has also been demonstrated by people (schools, businesses, associations and private citizens) through an adoption program initiated 15 years ago by a non-profit organisation, and has contributed to stewardship initiatives.

Commercial hunting reduced the size of the beluga population by 90% prior to the establishment of a moratorium in late 1970s. Since then, there has been little or no recovery of the population. During the last 30-40 years, the SLE beluga population has faced a variety of anthropogenic stresses, including disturbance, noise, habitat loss and high levels of contaminants in its habitat, especially in its diet. Levels of persistent contaminants in SLE beluga are among the highest reported in marine mammals.

Over the last 20-25 years, studies have found elevated levels of contaminants, mostly of agricultural and industrial origin, in carcasses of SLE beluga (Massé *et al.* 1986). These contaminants have largely been attributed to the location of this beluga habitat, which is downstream from heavy industry and intensive agriculture around the Great Lakes and the SL River. The SLE beluga whales are more contaminated with several persistent organic contaminants including polychlorinated biphenyls (PCBs) and several organochlorine pesticides than their counterparts in the remote Arctic (Muir *et al.* 1990). Recent research has found that levels of several 'legacy' (regulated) contaminants have slightly but significantly decreased in beluga (Lebeuf *et al.* 2007). These results indicate the value of environmental monitoring in support of evaluating the efficacy of regulatory changes. However, increasing concentrations of polybrominated diphenyl ethers, a new family of persistent and toxic chemicals, have been reported in SLE beluga (Fig. 6)(Lebeuf *et al.* 2004).

While it is difficult to establish causal linkages between exposure to high levels of contaminants and the failure of this population to recover, several studies conclude that contaminants represent a significant risk to the health of belugas. Possible mechanisms of action include contaminant-related immunosuppression which could explain some of the disease-associated mortality observed (De Guise *et al.* 1995). In addition, exposure to high levels of polycyclic aromatic hydrocarbons (PAHs), a family of contaminants that are metabolically biotransformed by beluga, was put forward as an explanation for the highly prevalent cancers in these animals (Martineau *et al.* 2002).

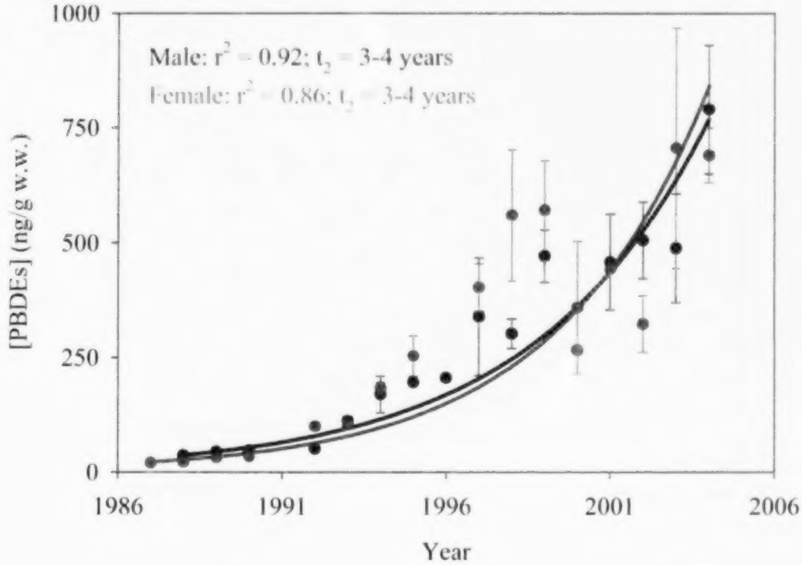

Figure 6: Change in ΣPBDE concentrations (ng/g, lipid weight) in St. Lawrence estuary beluga blubber. There was a clear exponential increase in ΣPBDE concentrations in both males and females between 1986 and 2004 with a calculated doubling time of 3-4 years (from Lebeuf et al. 2004 and unpublished data).

A carcass monitoring and necropsy program, financed in part by DFO, was launched in 1983. The high-profile program has provided valuable information by determining cause of death and providing tissues for contaminant analysis. However, complementary research activities are needed to better assess links between contaminants exposure and toxic effects. In addition, further research is needed to better characterize contaminant exposure in belugas. Currently, efforts are primarily focussed on contaminants that are persistent and/or regulated, such as those that accumulate in aquatic food webs and in beluga blubber. There is a need to further characterize beluga exposure to non-persistent and/or non-bioaccumulative toxic chemicals such as PAHs, to several new pesticides and to other chemicals not yet examined but expected to be found in beluga. In other words, toxic chemicals have to be monitored not only in beluga but also in its environment (e.g. water and sediments). Several of these contaminants are known to be present in the Great Lakes and are carried to the SLE by fluvial and atmospheric transport.

There is also a need to look at degradation products that are in some cases even more toxic than their parent compounds, e.g. hydroxy-PCBs. Some of these chemicals are bioaccumulated in beluga through their diet while others are produced within the animals through biotransformation. There is a need to improve our knowledge on the fate of contaminants within the animal once taken up by the beluga and the influence of life history. Biopsy sampling of live animals is an important and complementary approach which would add value to the carcass program.

So far, the risk for adverse health effects resulting from exposure of SLE beluga to contaminants has been based on a 'weight of evidence'. Although genotoxic and immunotoxic effects have been induced in arctic beluga cells exposed to concentrations of contaminants similar to those measured in SLE beluga tissues (Gauthier *et al.* 1999), it is difficult to extrapolate these results to the field. In this regard, epidemiological studies using biomarkers should be undertaken on free-ranging belugas. Such an approach would have provide more representative samples than those provided by dead individuals, that likely comprise a bias towards the very young, the old, stressed, malnourished and/or diseased animals. Such a strategy may add weight to the existing evidence and provide a useful direction for DFO research.

The current monitoring/necropsy program needs to be pursued and complemented with research activities on quantitative evaluation of histopathological lesions, used as biomarker (i.e. thyroid adenomatous hyperplasia). In addition, laboratory toxicity studies with surrogate species could provide relevant information to evaluate the toxic effect of contaminants (For example: (Fournier *et al.* 2000;Lapierre *et al.* 1999;Ross *et al.* 1996b;Ross *et al.* 1997)). A strategy which combines efforts on stranded belugas, free-ranging belugas, and surrogate species in the laboratory, offer perhaps the best approach to evaluating the health risks associated with exposure to contaminants in the SLE.

Research on contaminant levels, patterns and effects in the St Lawrence beluga population and its prey has been integral to multiple management-oriented processes:

- A Recovery Plan for SL beluga whales launched by DFO designed to tackle sources of chemical pollution;
- Development of an action plan (Plan d'Action St Laurent), a provincial-federal program to reduce the release of contaminants along the Lawrence River, in order to improve beluga habitat;
- Gremm (a local NGO) launched popular educational and stewardship programs for the beluga and the health and conservation risks associated with contaminants (programs such as Adopt-a-beluga);
- Development of the first Marine Park in Canada (SL-Saguenay) to limit activities and help the recovery of the beluga population;
- Research on currently-used flame retardants (PBDEs) in beluga whales is filling important datagaps in technical guidance documents that have been prepared for regulatory decisions in Canada (Canadian Environmental Protection Act - CEPA);
- Development by DFO of a Marine Protected Area (MPA) to expand the boundaries of the current SL-Saguenay marine park to better protect SL beluga habitat (such a zone limits human activities including contamination sources).

4.2 *Case study 2:* Arctic marine mammals: An interwoven tale of climate change contaminant risks

Mercury and climate. Global climate change models indicate the potential for substantial changes in many components of the Arctic environment, including temperature, precipitation, winds, ocean currents, lake and river hydrology, and snow and ice cover. These changes will clearly alter the complex atmospheric, hydrologic, and oceanographic pathways by which Many

persistent organic pollutants (POPs) and trace metals (including mercury (Hg)) are delivered to the Arctic, distributed, and concentrated (Macdonald *et al.* 2005). Although considerable progress has been made towards linking contaminant sources, pathways, and levels in Arctic systems, we now recognize that climate change may alter the systems and ecological processes themselves, changing contaminant pathways and interactions in ways that are currently difficult to predict. Concentrations and trends in environmental compartments and wildlife food species will be more complicated to interpret because they will not simply reflect trends in atmospheric transport or the effectiveness of international action. It is possible that climate variability and change in recent decades is responsible, at least in part, for some of the apparent temporal trends in contaminant levels (Macdonald *et al.* 2005;Stern and Macdonald 2005;Outridge *et al.* 2005;AMAP 2003). Thus, it is profoundly important that climate-induced process and pathway changes be recognized and accounted for in terms of their consequences for contaminants and the health of Arctic aquatic ecosystems.

Mercury (Hg) has long been known as a neurotoxin, and is emerging as a critical contaminant issue in the Arctic. In the western Arctic the issue is clear; marine mammals including seals and belugas have exhibited increasing Hg concentrations during the past two decades for as yet un-ascribed reasons (Wagemann *et al.* 1996;Lockhart *et al.* 2005;Wagemann *et al.* 1995). Hg concentrations in the liver of beluga whales from the Beaufort Sea area have been measured since 1982, peaking at 29.0 µg/g (wet wt., age corrected; 41.5 µg/g without age correction) in 2002 (Lockhart *et al.* 2005) (Fig. 7). Recent results show that some Hg concentrations in the liver of ringed seals from Holman, Sachs Harbour and Tuktoyaktuk are as high as 200 µg/g (Stern, unpublished results; 2004 collections). Arctic marine mammals bioaccumulate mercury to levels that are associated with adverse effects in other species (AMAP 2003).

Following the discovery of mercury depletion events (MDEs) in the Arctic, mercury has become a focus of international research (Schroeder *et al.* 1998;Lu *et al.* 2006). Although photo-chemically mediated MDEs remove gaseous Hg from the lower atmosphere after polar sunrise (Steffen *et al.* 2005) and deposit it to surfaces in a reactive, biologically available, form (Lindberg *et al.* 2002), the mechanisms and conditions that cause these MDEs remain unclear (Steffen *et al.* 2005). Further research to evaluate the impact of such events on the fate of Hg in arctic food webs is needed, particularly with a changing climate.

This leaves us without a basis to understand or manage the Hg that may threaten western beluga and other stocks. Other than MDEs, there appear several plausible mechanisms to explain how Hg threatens marine mammals in the western Arctic (Macdonald *et al.* 2005); these include:

1) Higher contaminant loads via human emissions;

2) Climate related release of Hg from terrestrial systems undergoing permafrost melting and increasing riverine imputs;

3) Climate related production of methyl Hg from sediments or water in either terrestrial or aquatic systems; and

4) Altered foraging of large animals or their prey.

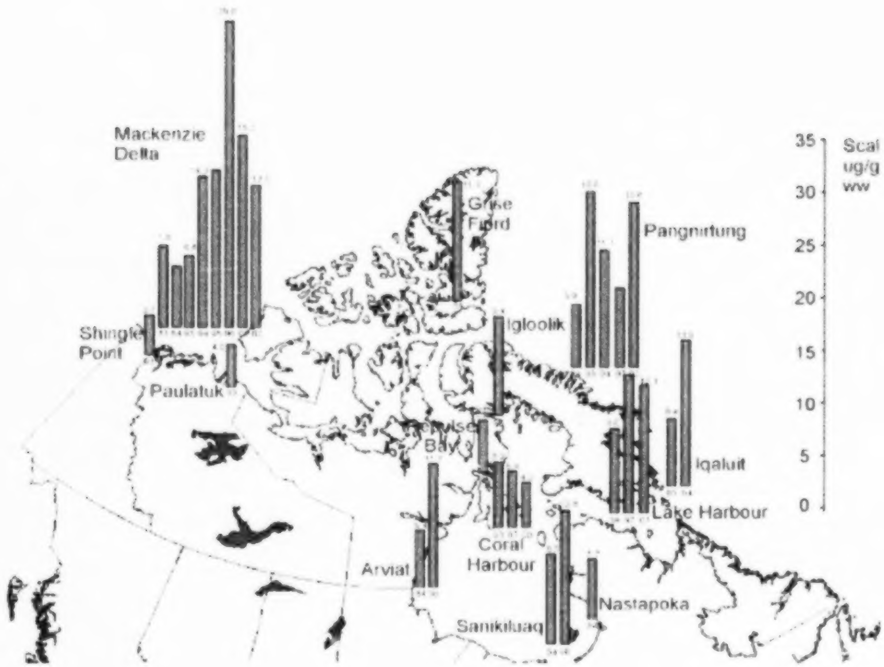

Figure 7: Mercury concentrations in liver (µg/g wet wt) of beluga whales in the Canadian Arctic (age corrected to 13.1 years) (Lockhart *et al.* 2005).

If climate-related factors are the cause for Hg trends in the western Arctic, then it is almost assuredly linked with aquatic release, cycling and transformation of Hg. Detailed understanding is required before we can project the risk from Hg to arctic ecosystems as a component of climate change – for example, the proposed Marine Protected Area at the mouth of the Mackenzie River appears to be a location which is vulnerable to escalating mercury. On the other hand, Hg may turn out to be a sensitive indicator of climate change, be it within the upstream drainage basins of the Arctic or within the Arctic Ocean itself. Detailed aquatic Hg measurements (total and methyl mercury) are urgently needed to produce a budget for Canadian waters in particular and the Arctic Ocean in general, and research that resolves the mechanisms of mercury entry into ecosystems. As a bioaccumulative metal which is highly toxic to mammals, Hg represents an important priority for research in the Arctic.

Persistent organic pollutants (POPs). Marine mammals also accumulate (relatively) high concentrations of POPs. Recently, spatial and temporal trend results for major POP groups and compounds were reported for beluga (Stern *et al.* 2005a;Stern *et al.* 2005b). With few exceptions, POP levels have declined, as evidenced in male Arviat beluga whales over the period between 1986 and 2003. The 2003 animals are about twice the age of those collected in 1986 and 1999 but, if corrected for age, would most likely still result in lower levels. Conversely, and as observed for mercury, maximum POP concentrations in Hendrickson Island animals are observed in samples collected during the mid-1990s (1994-1996). As was postulated for mercury, the

higher POP concentrations in the mid-1990s could be attributed to recent changes in ice cover in the western Arctic Ocean which may, for example, alter the foraging of the beluga whales or their prey (Stern and Lockhart 2006). Again, as with mercury, POP concentrations in these animals have now reached levels that may cause effects in other species (AMAP 2003).

Emerging brominated and fluorinated contaminant concerns. Fluorinated organic compounds (FOCs) such as PFOS and its precursors have increased significantly over time in western Arctic biota. For example, concentrations of PFOS increased linearly from 1982 to 2002 in beluga liver from Pangnirtung with a mean level of about 20 ng/g ww in 2002 (Tomy *et al.* 2005). Levels of the PFOS precursor PFOSA were higher than PFOS and also increased linearly from 1982 to 2002 with mean levels of about 70 ng/g ww in 2002 (Tomy *et al.* 2005). ΣPBDE and BDE47 (the predominant PBDE congener in many environmental matrices) increased by 6.8 and 6.5 fold, respectively, over the period from 1982 – 1997 (Stern and Ikonomou 2000). Both FOCs and BFRs were recently shown to biomagnify in an eastern Arctic marine food web (Tomy *et al.* 2004) and therefore, like Hg and POPs, pose a significant risk to Arctic marine ecosystem health (AMAP 2003).

Stock identification using contaminant patterns. Present stock boundaries of narwhal and beluga are not well understood. The management of these marine mammals has changed from quota to a reporting-based system for some hamlets. However, neither the quota nor the reporting system is based on knowledge of stock delineation or estimates of sustainable takes for stocks. HOC levels in marine mammal blubber depends on what an animal has eaten during its lifetime, age, sex, reproductive history in females, what species of animal it eats, and the history and food chain position of the animals that are being eaten. To date, HOC levels and ratios have been successfully used to compare beluga samples in high Arctic and Greenland beluga (Innes *et al.* 2002), and Alaska and Beaufort Sea belugas (Krahn *et al.* 2000). More recently, results from beluga landed at Kimmirut, Iqaluit and Pangnirtung showed that these beluga come from either two or three stocks instead of the one stock that had been previously used in management (de March *et al.* 2004). Recent findings for Narwhal are also very encouraging and are discussed in detail in a recent report (de March and Stern 2003). This analysis showed that contaminant patterns can separate narwhals from different summering areas.

Research on contaminant levels, patterns and effects in Arctic marine mammals and their prey has been integral to multiple management-oriented processes:

- Canada's leadership role in the development and adoption of the Stockholm Convention to phase out priority POPs;
- The design and implementation of Large Ocean Management Areas (LOMAs) and Marine Protected Areas in the Beaufort Sea under the terms of the Oceans Act;
- Understanding the effects of climate change and mercury cycling on the health of marine mammals in the western Canadian Arctic (Fisheries Joint Management Committee);
- The identification of at least three groups of beluga in the Southeastern Baffin Region (Cumberland Sound, Kimmirut and Iqaluit) in support of their management as separate "stocks".

4.3 *Case study 3:* British Columbia's killer whales (*Orcinus orca*)

British Columbia's killer whales are highly valued by local citizens, ecotourists, and First Nations communities. There is little doubt that this cetacean symbolizes coastal British Columbia. The killer whale ecotourism industry contributes nearly $ 100 million annually to the British Columbia economy, representing a substantial renewable resource which provides more economic benefit than the commercial wild salmon fishery.

The 2001 listing of the southern resident community (n=85) as 'endangered', the northern residents (n=200) as 'threatened', and the transients (n=200) as 'threatened' reflected the mounting conservation threats to these reproductively isolated populations. Noise and disturbance, diminishing prey abundance (primarily Chinook salmon), and very high toxic chemical concentrations, underlie the listings of the resident killer whales (http://www.cosewic.gc.ca/eng/sct2/index_e.cfm). In the case of contaminants, a DFO-led study established the transients and southern residents as among the most PCB-contaminated marine mammals in the world, surpassing the endangered St Lawrence belugas by a factor of 2-4 times (Ross *et al.* 2000). A follow-up study using the same samples found moderate levels of flame retardants including the currently-used polybrominated diphenylethers (PBDEs)(Rayne *et al.* 2004).

The southern resident population is particularly vulnerable to human impacts. Plying the industrialized Strait of Georgia (southern BC) and Puget Sound (northern Washington State) during their summer feeding season (May through October), these whales are exposed to the activities of a burgeoning human population (8 million people in the BC, Canada - Washington, USA region)(Fig. 8). Local, regional and international contaminant inputs via point source discharges and non-point source contamination continue to deliver contaminants to their food web. A combination of 'local' (~non-salmonid) and 'global' (~imported from the North Pacific Ocean by salmon) sources of contaminants are thought to be responsible for the contamination of killer whales (Ross *et al.* 2000), although the relative importance of each respective source is presently unclear. In order to reduce health risks associated with contaminants, further research is needed to document source, transport and fate processes for different contaminants in NE Pacific food webs as it pertains to exposure to complex contaminant mixtures by marine mammals.

Large animals with large habitat needs are difficult to study. DFO research in the Pacific Region has been pursuing three strategies to document the effects of contaminants on the health of killer whales. Firstly, participation in an international working group led to the formulation of a new integrated ecological risk assessment framework using a marine mammal example (Ross and Birnbaum 2003). This provides a basis for a 'weight of evidence' approach in ecotoxicology and in ecological risk assessment. Secondly, the harbour seal has been used as a surrogate species to characterize the risk of contaminant effects in killer whales, akin to the use of laboratory animals as surrogates for human toxicology. And thirdly, novel biomarker approaches are being developed to assess the health of free-ranging killer whales by measuring vitamins, enzymes, hormones and hormone receptors in small skin/blubber biopsies.

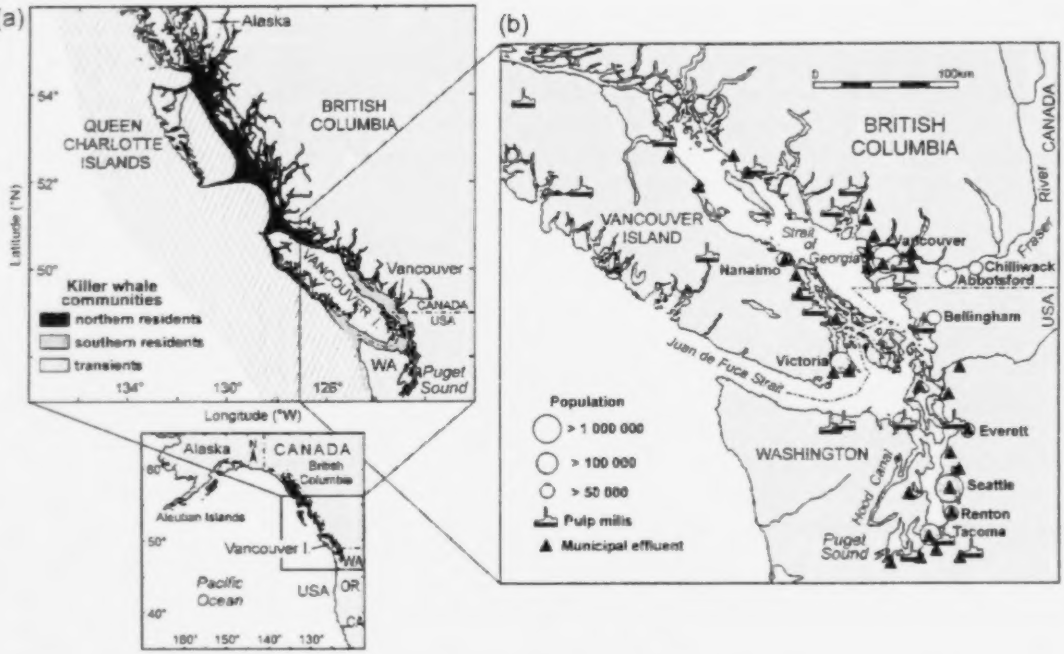

Figure 8: British Columbia's reproductively isolated killer whale (*Orcinus orca*) communities include the marine mammal-eating transients (threatened), and the fish-eating northern (threatened) and southern residents (endangered) (Ford *et al.* 1998). The Georgia Basin (BC)-Puget Sound (USA) waters represent summer feeding habitat the ~ 85 southern resident killer whale individuals, who must share this coastal region with approximately 8 million humans. From (Ross 2006).

While toxicological research in killer whales is not impossible, it is difficult and costly. In the Pacific Region, the smaller and non-migratory harbour seal is helping us to better understand the contamination of local killer whale habitat quality and to provide more substantial evidence that contaminants are a health risk for marine mammals. In this way, harbour seal research has clearly identified the Puget Sound region as a PCB hotspot, and is helping to guide remediation and source control efforts to protect killer whales. In addition, adverse health effects noted in several harbour seal studies underscore the risk that PCBs pose to killer whales.

Evidence now suggests that contaminants are affecting harbour seal health in British Columbia, such that current levels of POPs represent a tangible risk to free-ranging marine mammals (Table 1). Since they are approximately 10-fold more POP-contaminated than local harbour seals, the region's killer whales appear to be highly vulnerable to health effects (Fig. 9). Additional research is needed to further validate and apply health biomarkers in killer whales, and to evaluate the relative importance of multiple stressors on the health of these marine mammals.

Table 1: Persistent organic pollutants (driven largely by the PCBs) have recently been found to be disrupting several immune function and endocrine processes in free-ranging harbour seals in British Columbia and Washington State, highlighting concerns about population-level effects in this marine mammal and in the region's heavily contaminated killer whales.

Endpoint measured in harbour seals	***Effect***	***Reference***
Immune function	↓	(Mos *et al.* 2006)
Vitamin A concentration (in circulation)	↓	(Simms *et al.* 2000;Mos *et al.* 2007)
Vitamin A receptor expression in blubber (RARα)	↑	(Mos *et al.* 2007)
Thyroid hormone concentrations (in circulation)	↓	(Tabuchi *et al.* 2006)
Thyroid hormone receptor expression in blubber (TRα)	↑	(Tabuchi *et al.* 2006)

At present, a 'weight of evidence' suggests that killer whales are at risk for adverse health effects, including immunotoxicity, reproductive impairment, and endocrine disruption. The PCBs continue to represent the contaminant class of greatest concern to the health of killer whales and other marine mammals in British Columbia, but their environmental concentrations have been slowly declining since the adoption of regulations and source controls in the 1970s. However, the production and use of one PBDE product (deca-BDE formulation) continues in North America. Exponential trends observed in environmental concentrations of this persistent and endocrine-disrupting compound suggest that the PBDEs may surpass the PCBs as the pre-eminent POP of concern in the region over the next two decades (Rayne *et al.* 2003;Elliott *et al.* 2005). Research is needed to characterize the extent to which killer whales are exposed to PBDEs and other emerging contaminants, and to evaluate the possible health effects of this exposure (Ross 2006).

Resident killer whales feed almost exclusively on salmon, highlighting the importance of protecting salmon stocks both at sea and in their spawning/rearing areas. Since salmon in British Columbia often spawn in agricultural or forested areas, the application of current-use pesticides (CUP) may adversely affect salmon health and abundance (Tierney *et al.* 2006;Verrin *et al.* 2004;Tierney *et al.* 2007). Research into the effects of CUPs on marine mammal prey is important, since most CUP are less bioaccumumulative and persistent than POPs, and may ultimately reduce the prey base for marine mammals.

Research on contaminant levels, patterns and effects in BC's killer whales and their prey has been integral to multiple management- and policy- oriented processes:

- The SARA (DFO)-launched Killer Whale Recovery Team designed a comprehensive Recovery Strategy to tackle sources of chemical and biological pollution;
- Several NGO's have adopted educational programs and strategies to reduce the contamination of killer whale habitat (Georgia Strait Alliance's '*Green Boating Program*', Sierra Club's pesticide-free '*Killer Whale friendly lawn*' campaign);

- Harbour seal and killer whale contaminant 'indicators' have been adopted by several ecosystem indicator working groups to foster measures which protect local killer whale habitat (Georgia Basin and Puget Sound):
    - British Columbia State of the Environment Report chapter on 'Persistent Organic Pollutants in harbour seals': www.env.gov.bc.ca/soe/bcce/;
    - Washington State State of the Sound report including chapter on 'Toxics in harbor seals': http://www.psat.wa.gov/Publications/state_sound07/sos.htm;
    - the multi-agency / binational Georgia Basin – Puget Sound transboundary Ecosystem Indicators chapter on 'Toxics in harbour seals': http://www.epa.gov/region10/psgb/indicators/.
- EC and DFO are creating a new web-based information and mapping tool (the Pacific Contaminants Atlas) for contaminant sources in the Strait of Georgia as part of Georgia Basin Action Plan (GBAP) management/stewardship efforts to protect local killer whale habitat;
- Studies of dioxins and furans reveal a dramatic decline in levels of dioxins and furans (up to 95%) in the BC marine environment following the implementation of source controls at pulp and paper mills in the late 1980s;
- Studies on current use pesticide (CUP) measurements and effects in coho salmon from BC's Fraser Valley are providing the Pest Management Regulatory Agency (PMRA) and DFO with guidance on current pesticide regulations as they relate to salmon habitat;
- Research on currently-used flame retardants (PBDEs) in killer whales, harbour seals, salmon, and other wildlife are filling important datagaps in technical guidance documents that have been prepared for regulatory decisions in Canada (CEPA), the State of Washington, and other jurisdictions;
- The US federal government and the State of Washington have announced major new clean-up initiatives in Puget Sound to reduce PCB inputs and improve local killer whale habitat quality.

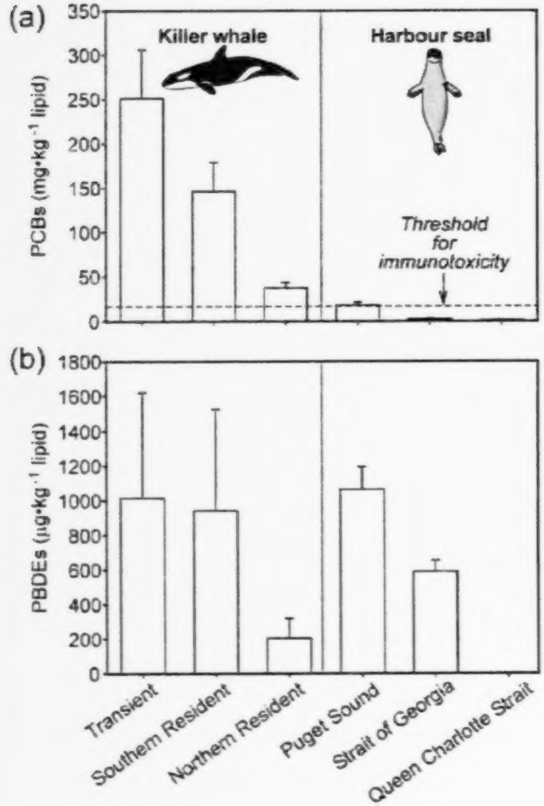

Figure 9: British Columbia's killer whales (*Orcinus orca*) and harbour seals (*Phoca vitulina*) are exposed to high levels of the regulated polychlorinated biphenyls (PCBs) and moderate levels of the emerging polybrominated diphenyl ethers (PBDEs). The PCB concentrations in the region's killer whales easily surpass established toxicity thresholds, including one for immunotoxicity in harbour seals (17 mg•kg-1), suggesting that these killer whales are at risk for PCB-related effects. (Data from (Ross *et al.* 2000;Ross *et al.* 2005;Rayne *et al.* 2004) and P.S. Ross, unpublished data).

5 Legislative rationale for DFO research on contaminants in marine mammals

5.1 Oceans Act (1999)

The Oceans Act establishes a need for an ecosystem-approach to science and management as they related to Canada's three oceans. In this sense alone, marine mammals play an important role in the marine ecosystem. As large, long-lived consumers that rely on lower trophic level prey, the success of marine mammals depends on a healthy and productive ocean. As predators, the toothed marine mammals may also exert a top-down approach, and present a selective influence on prey populations.

Under the auspices of the three pillars of the Oceans Act (Marine Protected Areas [MPAs], Integrated Management [IM], and Marine Environmental Quality [MEQ]), marine mammal toxicology may be seen as an important component of the MEQ process of providing science (research, monitoring and reporting) in support of MPAs and IM. Research on contaminants in marine mammals can contribute important and relevant MEQ information to integrated managers, MPA planners and stakeholders. Environmental contaminants that persist, accumulate in marine mammals, and adversely affect the quality (health) of marine mammals or their prey, should be characterized in an ecosystem context and incorporated into DFO's Oceans Act strategies.

5.2 Species at Risk (SARA)

Marine mammals figure prominently on Canada's endangered species agenda. Of the 69 mammals listed by Committee on the Status of Endangered Wildlife in Canada (COSEWIC; 1977) as extinct, endangered, threatened, or special concern, 33 are marine mammals. Canada's Species at Risk Act (SARA; 2003) establishes a legal framework for the identification, protection and recovery of wildlife species deemed at risk by the COSEWIC status report and the subsequent Recovery Strategy. Environmental contaminants can affect the health of marine mammals, resulting in population declines or impeding the recovery of endangered populations.

Recovery Planning under SARA must identify the major conservation threats to a listed species, and the steps that can be taken to mitigate these threats. In the case of environmental contaminants, scientific research is needed as the basis for these steps, since the Recovery Team for a given population or species must be able to i) identify the contaminant type of concern; ii) characterize the likely health impacts (or risks) to the population; iii) identify the source(s) of this contaminant; iv) prioritize contaminant threats vs other anthropogenic stressors; and v) design means to reduce inputs of this contaminant into marine mammal habitat. Such efforts inevitably involve partnering with stakeholders and OGDs, as contaminants may originate from point source practices (e.g. sewage and industrial outfalls) or non-point sources (e.g. agricultural and urban runoff, or atmospheric deposition).

5.3 Fisheries Act

The Fisheries Act comprises a number of regulations that are relevant to contaminants and marine mammals. Many regulations were designed to protect fish and fish habitat from the effects of pollution, and have targeted particular activities (e.g. Pulp and Paper Effluent regulations 1992; Chlor-alkali Mercury Liquid Effluent regulations 2004; Metal Mining Effluent regulations; 2002), although the release of any 'deleterious substance' (Sections 34-43) into fish habitat is prohibited. 'Marine mammals' are included as part of the 'fish' designation.

As upper level consumers in aquatic food webs, marine mammals are exposed to the cumulative impacts of countless point- and non-point sources (local, regional and global) and are not adequately protected by a documentation and regulation of point sources discharges. While DFO is increasingly viewing the water quality and contaminant-related regulations and sections of the Fisheries Act as an EC responsibility, the health effects associated with exposure of marine mammals to thousands of contaminants from countless point and non-point source contaminants remains a DFO concern. In addition, the absence of an EC scientific capacity on Canada's oceans further underscores the need for a DFO role in characterizing contaminant exposure in marine mammals, and the effects of these complex mixtures on their health. Solid DFO research on contaminant accumulation and contaminant-related health effects in marine mammals provides DFO managers with the information needed by EC and OGDs to better protect marine mammal habitat through the Fisheries Act.

6 DFO directions into the future: Research priorities

Characterizing the health impacts of toxic chemical exposure in marine mammals is not easy, and involves legal, ethical, scientific, logistical and public perception issues. While a 'weight of evidence' approach ultimately provides the most comprehensive basis for risk characterization, several avenues for cutting-edge marine mammal toxicology research exist that are relevant, deliver science of international calibre, provide for public interest, and do not unduly impact marine mammals. Such research must pay particular attention to the life history features of marine mammals, since the long lives of many species lead to the integration of contaminant trends over long periods of time. Priority strategies include:

1) *Conduct research on contaminants in marine mammal food webs and effects on marine mammal health.* This research should be carried out in support of Oceans Act (IM, MEQ), SARA (Recovery teams), Fisheries Act, Habitat programs, OGD clients (EC, HC, INAC), NGO clients, and international clients (USEPA, US NMFS/NOAA, Stockholm Convention signatories).

2) *Development and apply new biomarker techniques as non-invasive approaches for marine mammal toxicology.* Biomarker studies can provide opportunities to measure both contaminants and health endpoints using skin/blubber biopsies or blood samples. Multiple techniques have been developed, including measurements of vitamin A, thyroid hormones, cytochrome P450 enzymes and hormone gene receptor expression. Such tools require a field capacity combined with specialized toxicological laboratories (cell culture facility; molecular technique capacity; analytical labs). Such an approach is consistent with the DFO Biotechnology Strategy.

3) *Adopt a suite of in vitro and in vivo approaches to assessing the health effects of toxic chemicals.* Approaches may comprise the use of marine mammal cell lines, or captive feeding (yet ethically acceptable) studies of harbour seals. The harbour seal has been extensively used in Europe and Canada for minimally-invasive toxicological research in captive, semi-field and field situations. This species is relatively easy to manage, is well understood, and is widely distributed in temperate Atlantic and Pacific coastal waters.

4) *Characterize confounding factors to ensure the quality and relevance of marine mammal toxicology and ecotoxicology studies.* Factors including age, sex, season, stress, condition and life history can affect both contaminant concentrations and health endpoints being measured, and must be taken into account in marine mammal toxicology. There is a need to improve the science of measuring health of marine mammals and documenting contaminant-related health effects.

5) *Identify emerging contaminants that may present a health risk to marine mammals.* This research is an important part of ensuring healthy ocean habitat for all biota. Despite past regulatory successes (e.g. PCBs, DDT, dioxins and furans), emerging chemical concerns (e.g. mercury, current-use pesticides, flame retardants) continue to enter the aquatic environment, where they may affect marine mammal health or the health of their prey. A proactive analytical capacity, ecosystem-based study design, careful attention to sampling strategies, and collaboration with external partners should form part of this strategy for DFO Science.

6) *Consider the conservation implications of contaminants, and place these in the context of other anthropogenic stresses (e.g. vessel noise, disturbance, food availability, habitat change, climate change and harvesting).* There is a need for studies to evaluate the relative roles of different anthropogenic factors, and for management and stakeholders to consider multiple factors facing free-ranging populations. In this way, research will be conservation-oriented and will enable mitigation under the auspices of SARA and the Oceans Act.

7) *Conduct research on the implications of climate change for altered contaminant pathways in the environment and in food webs, and for the potential for heightened health risks to marine mammals.* A detailed understanding of how contaminant exposure occurs, especially in vulnerable ecosystems such as the Arctic is required before DFO can project the risk from contaminants to Arctic ecosystems as a result of climate change. Such efforts should include contaminant measurements in marine mammals and their habitat, but must take into account changing baselines in e.g. ice cover, ocean productivity, migratory routes and behaviour. Efforts can also involve the application of pharmacokinetic models to marine mammals to predict temporal trends, recovery after / response to regulations, and effects of life history.

8) *Strengthen linkages to partners and clients so as to better protect marine mammal health and marine mammal habitat.* These clients include both internal (e.g. Center of Expertise

for Marine Mammals - CEMAM, Habitat, SARA) and external (public, NGOs, media) sectors.

7 Conclusions

Canada's marine mammals represent an important resource to Canadians, generating social, economic, ecological, and intrinsic benefits via ecotourism, harvesting, and traditional foods for Inuit and First Nations communities. The conservation and protection of marine mammals fulfills an important part of DFO's mandate. Being vulnerable to contamination by POPs and mercury, some populations of marine mammals in Canada have suffered from endocrine disruption, resulting in reduced reproductive performance and increased vulnerability to disease. In addition, long-lived marine mammals can provide an integrated overview of marine ecosystem health and offer important guidance on qualitative and quantitative aspects of coastal food webs.

Protecting marine mammals and their habitat is fraught with challenges. However, a number of success stories demonstrate that research in the area of contaminants in marine mammals is relevant and leads to effective public policy. Examples include:

- the adoption of the Stockholm Convention as international law followed Canada's leadership role in conducting research on contaminants in Arctic food webs;
- Recovery Teams launched under SARA for St Lawrence belugas and BC killer whales are tackling chemical and biological pollution sources in efforts to recover these species;
- The regulatory elimination of PCBs and DDT in the 1970s has led to dramatic reductions of these persistent endocrine-disrupting chemicals in marine mammals in all of Canada's oceans;
- Current research findings on mercury loading and processes in Arctic marine ecosystems are being used as evidence in an effort to secure an international treaty to control mercury emissions;
- Source control and regulations dramatically reduced releases of dioxins and furans from pulp and paper plants in Canada, with a subsequent improvement of coastal habitat quality for fish and marine mammals;
- Regional, multi-agency, action plans have identified contaminant concerns, sources, impacts and mitigative strategies to reduce point and non-point source pollutants into marine mammal habitat including the Arctic, St Lawrence, Puget Sound and Georgia Basin.
- Research and advice on currently used chemicals including flame retardants (PBDEs) and pesticides in marine mammals and their prey (PMRA) are being delivered to local and national government departments in Canada and the USA in support of regulatory decisions.

In short, DFO is uniquely poised to conduct cutting-edge scientific research that answers to its mandate under the terms of the Oceans Act, SARA, the Fisheries Act, international obligations,

and its role as 'steward' for Canada's oceans. As 'sentinels' of marine ecosystem health, marine mammals can provide a signal of the cumulative impacts of environmental contaminants on ocean ecosystems, and deliver such information with relative ease to the general public and stakeholders via various media.

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